



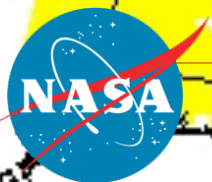
# Satellite Remote Sensing of Particulate Matter Air Quality

**Pawan Gupta**

Satellite Remote Sensing of  
Particulate Matter Air Quality: Data,  
Tools, Methods and Applications (Aka  
AOD-PM)

**ARSET**

**Applied Remote Sensing Training**



A project of NASA Applied Sciences

## OBJECTIVE

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**Estimation of PM<sub>2.5</sub> mass concentration at surface ( $\mu\text{gm}^{-3}$ ) while utilizing satellite derived Aerosol Optical Depth (AOD – unitless quantity) at visible wavelength**



## AIR QUALITY INDEX

Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous

# What are we looking for ? & Why ?

## AIR QUALITY INDEX

Best  
7 AM

Worst  
6 PM

PLEASE  
BURN  
CLEANLY

Unhealthful

Poor

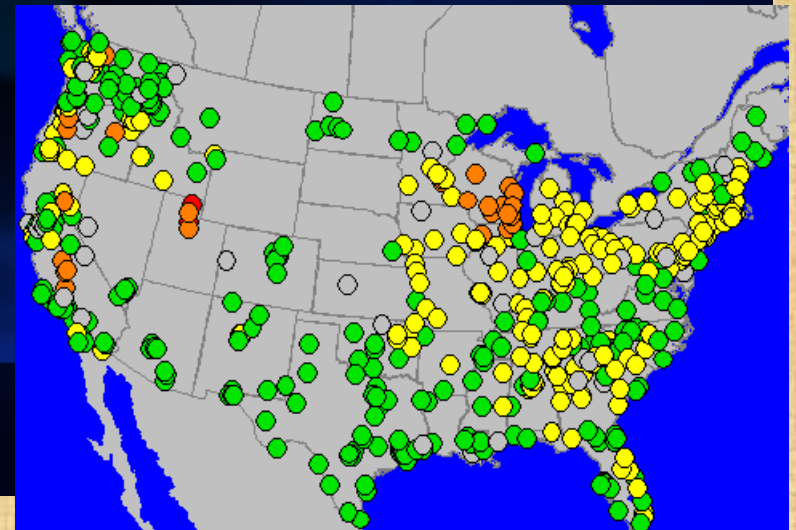
Moderate

Good

30  
Low

58  
High

## Spatial Gaps



January 23, 2009 12:00 am EST

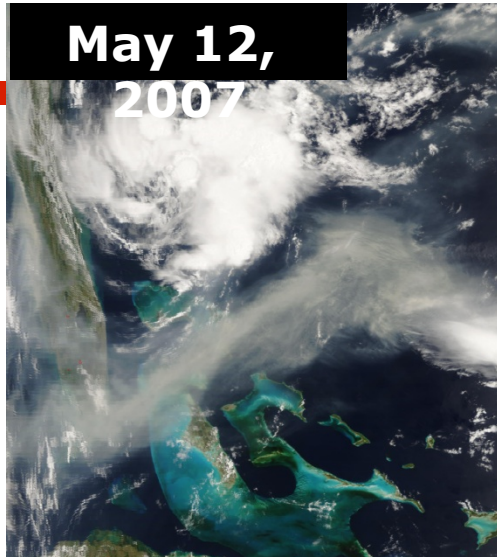


# MODIS-Terra True Color Images

**May 11,  
2007**



**May 12,  
2007**



**May 13,  
2007**



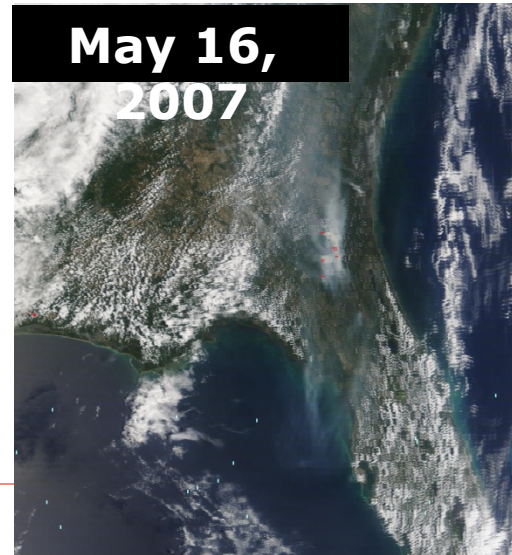
**May 14,  
2007**



**May 15,  
2007**



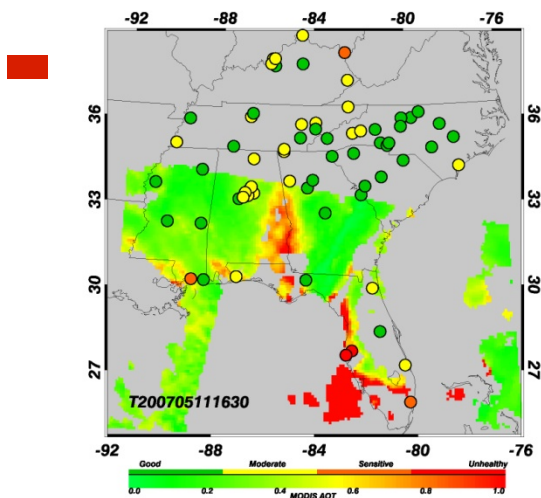
**May 16,  
2007**



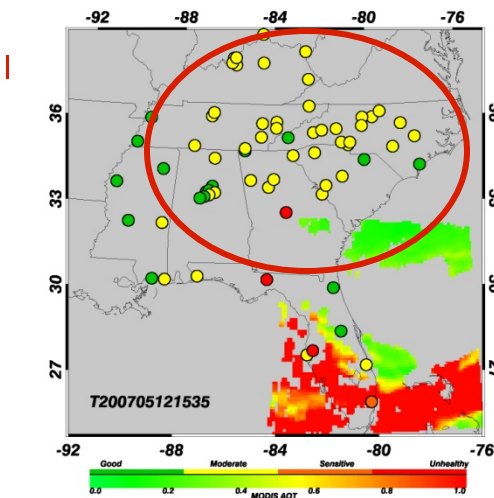


# MODIS-Terra Aerosol Optical Thickness

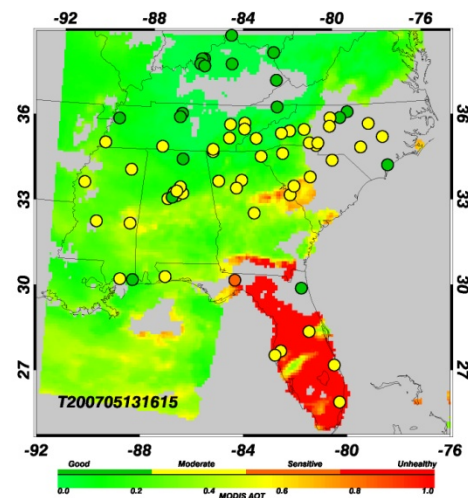
May 11, 2007



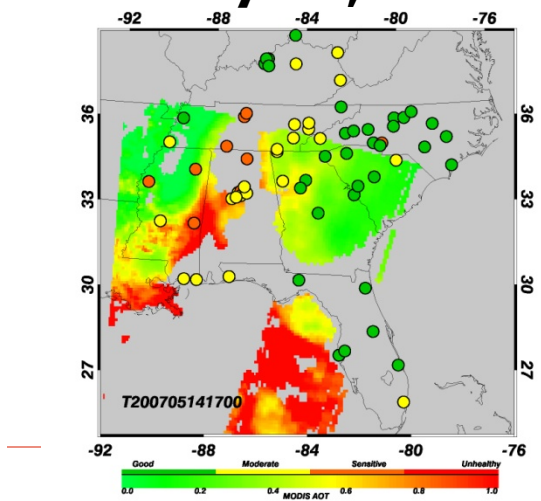
May 12, 2007



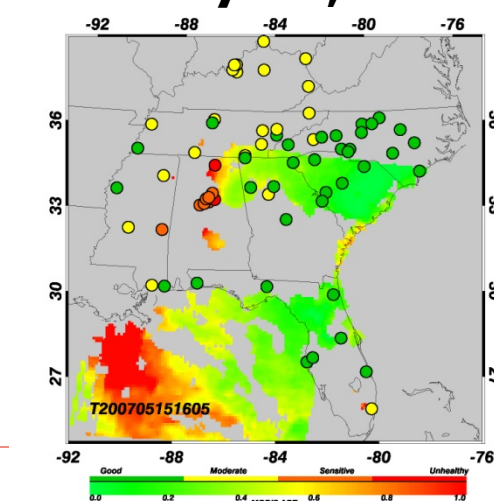
May 13, 2007



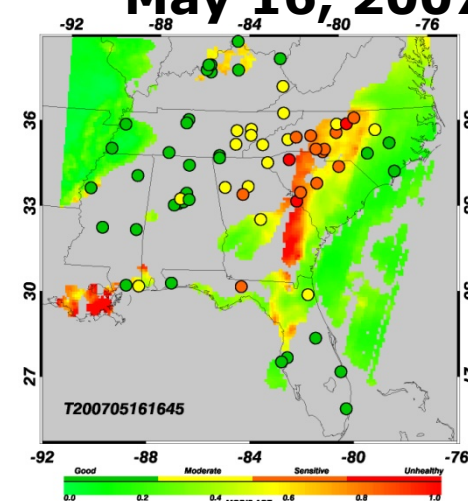
May 14, 2007

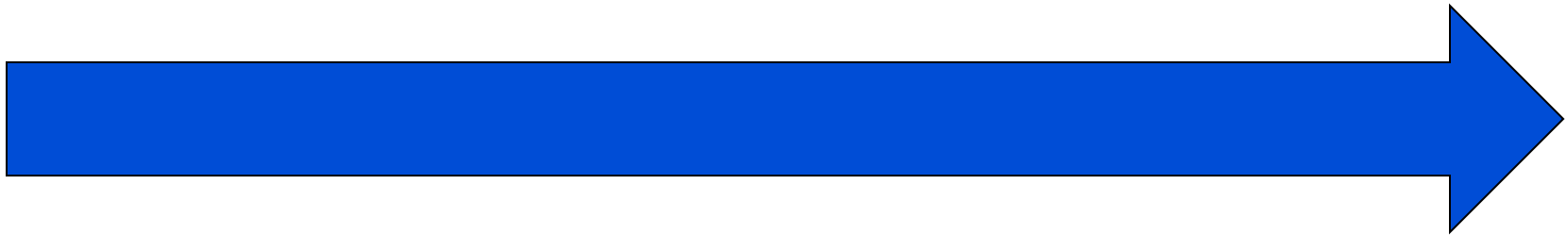


May 15, 2007



May 16, 2007



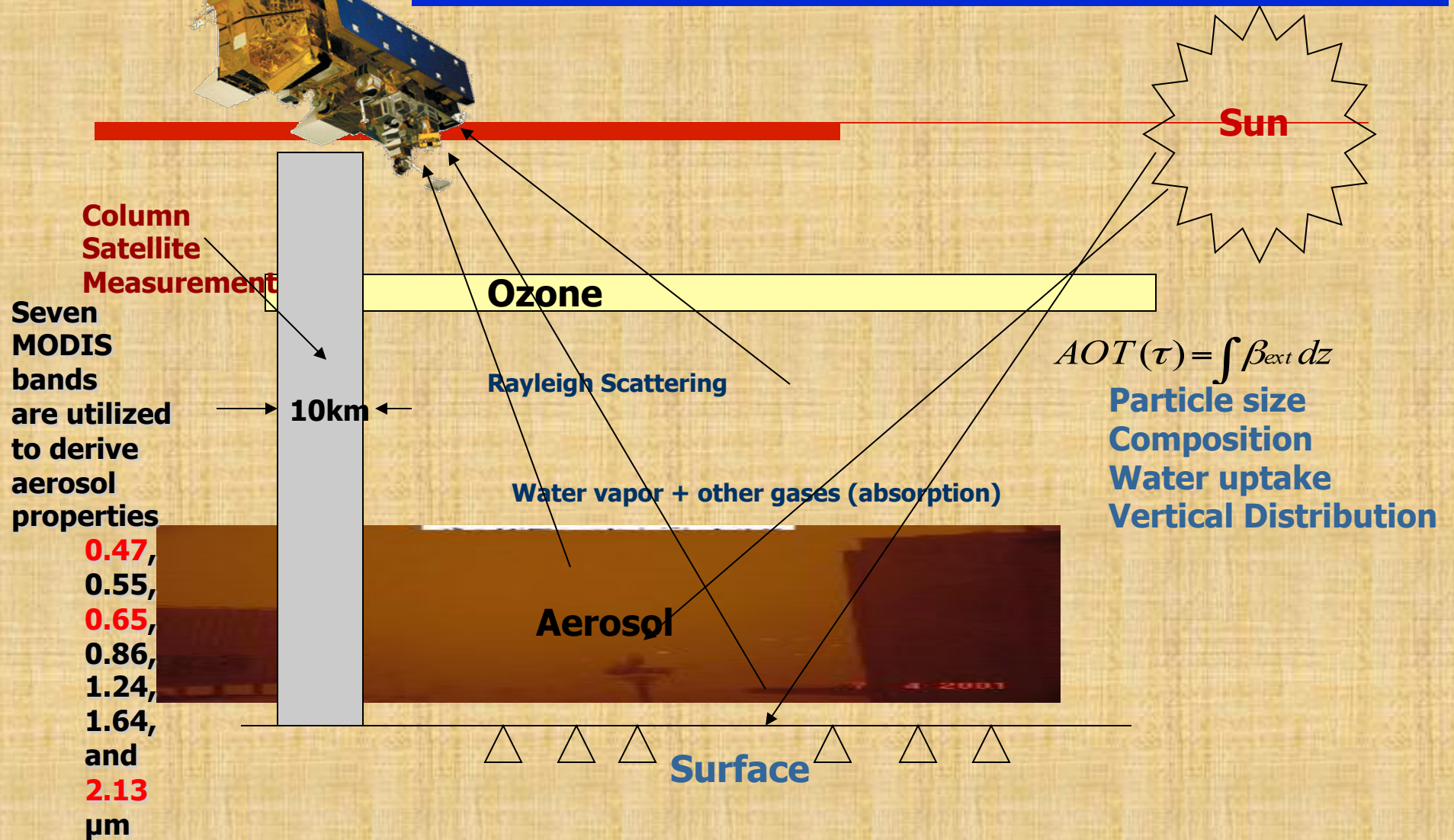


**AOD (or AOT) to PM**



**Satellite**

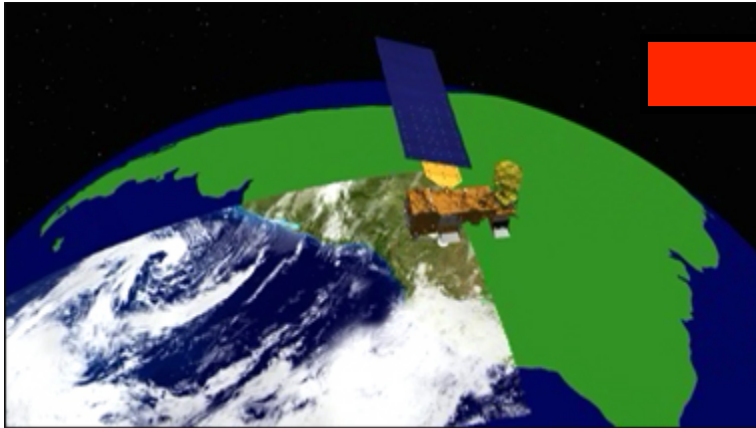
# What Satellite Provides?



**Satellite retrieval issues - inversion (e.g. aerosol model, background).**



# Measurement Technique



**AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unitless. AOD is function of shape, size, type and number concentration of aerosols**



**PM2.5 – Mass per unit volume of aerosol particles less than 2.5  $\mu\text{m}$  in aerodynamic diameter at surface (measurement height) level**

# AOD – PM Relation

$$AOD(\lambda) = \int_{\text{surface}}^{\text{Top-of-Atmosphere}} \beta_{ext,p}(\lambda, z) dz$$

$$C = \frac{4\rho r_e}{3Q} \times \frac{f_{PBL}}{H_{PBL}} \times AOD$$

□  $\rho$  – particle density

□  $Q$  – extinction coefficient



**Composition**

□  $r_e$  – effective radius



**Size distribution**

□  $f_{PBL}$  – % AOD in PBL

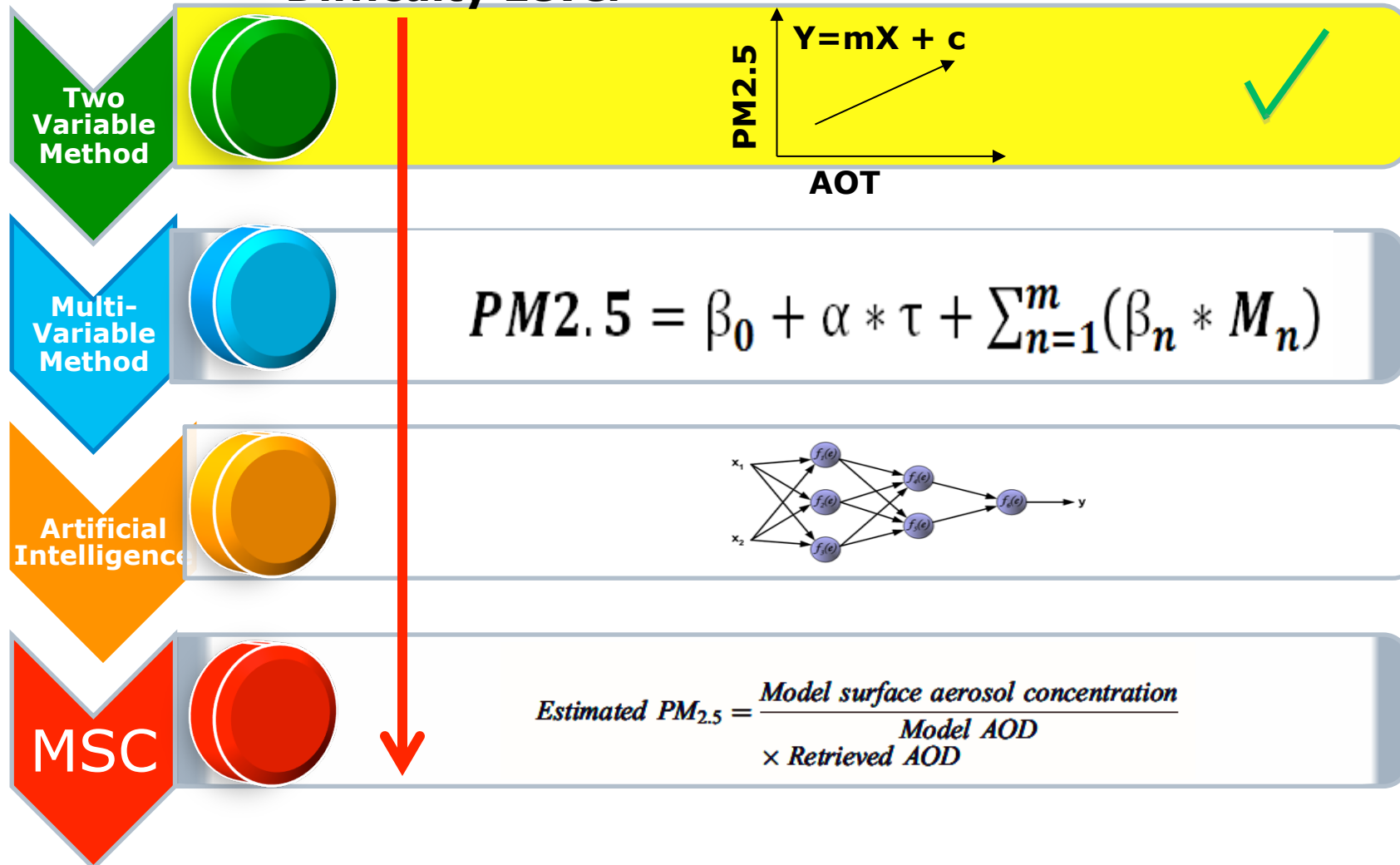


**Vertical profile**

□  $H_{PBL}$  – mixing height

# PM2.5 Estimation: Popular Methods

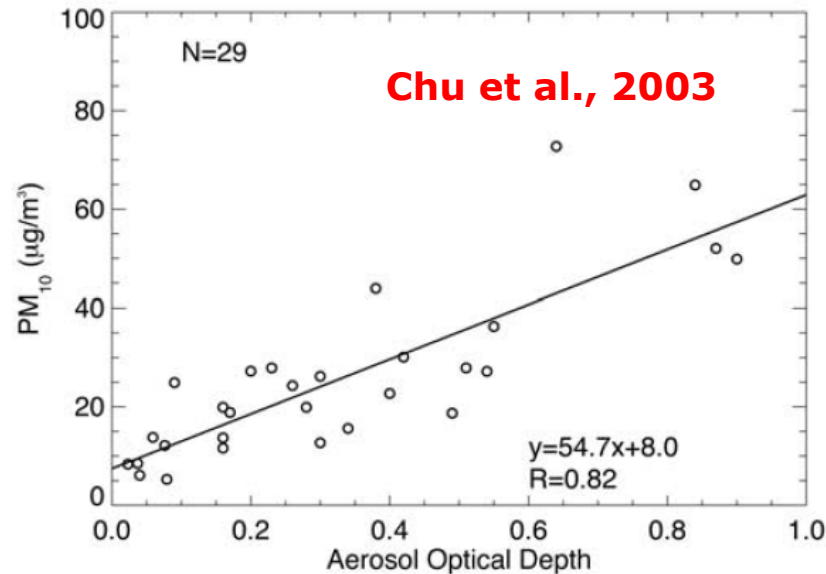
Difficulty Level



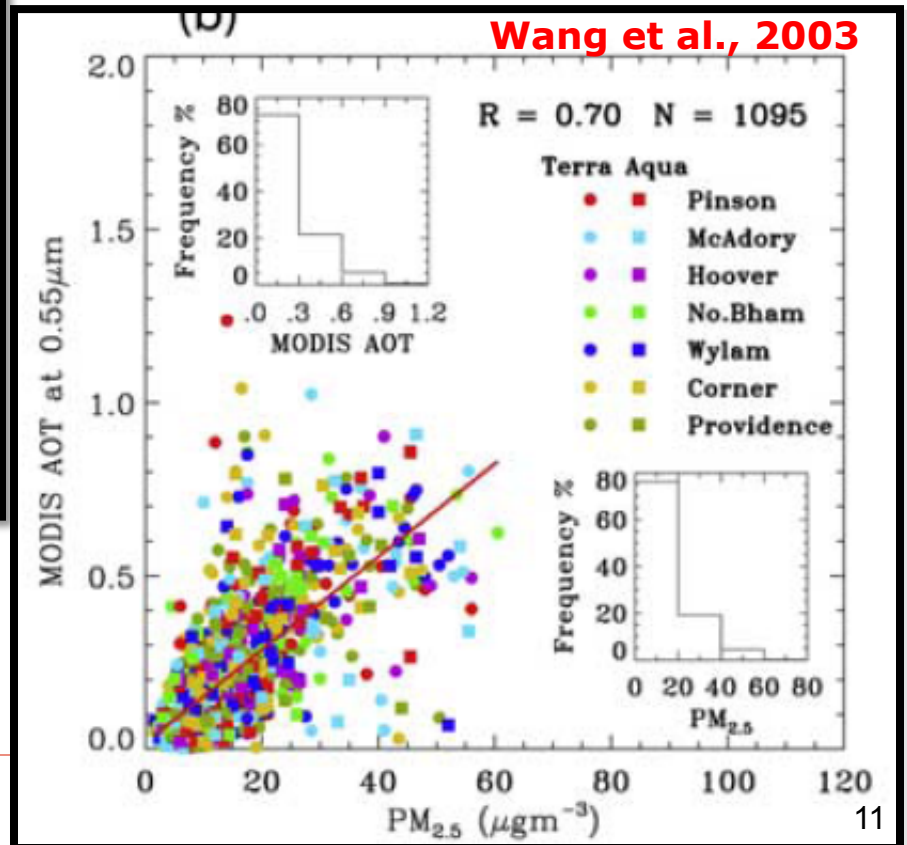
and Empirical Methods, Data Assimilation etc. are under utilized



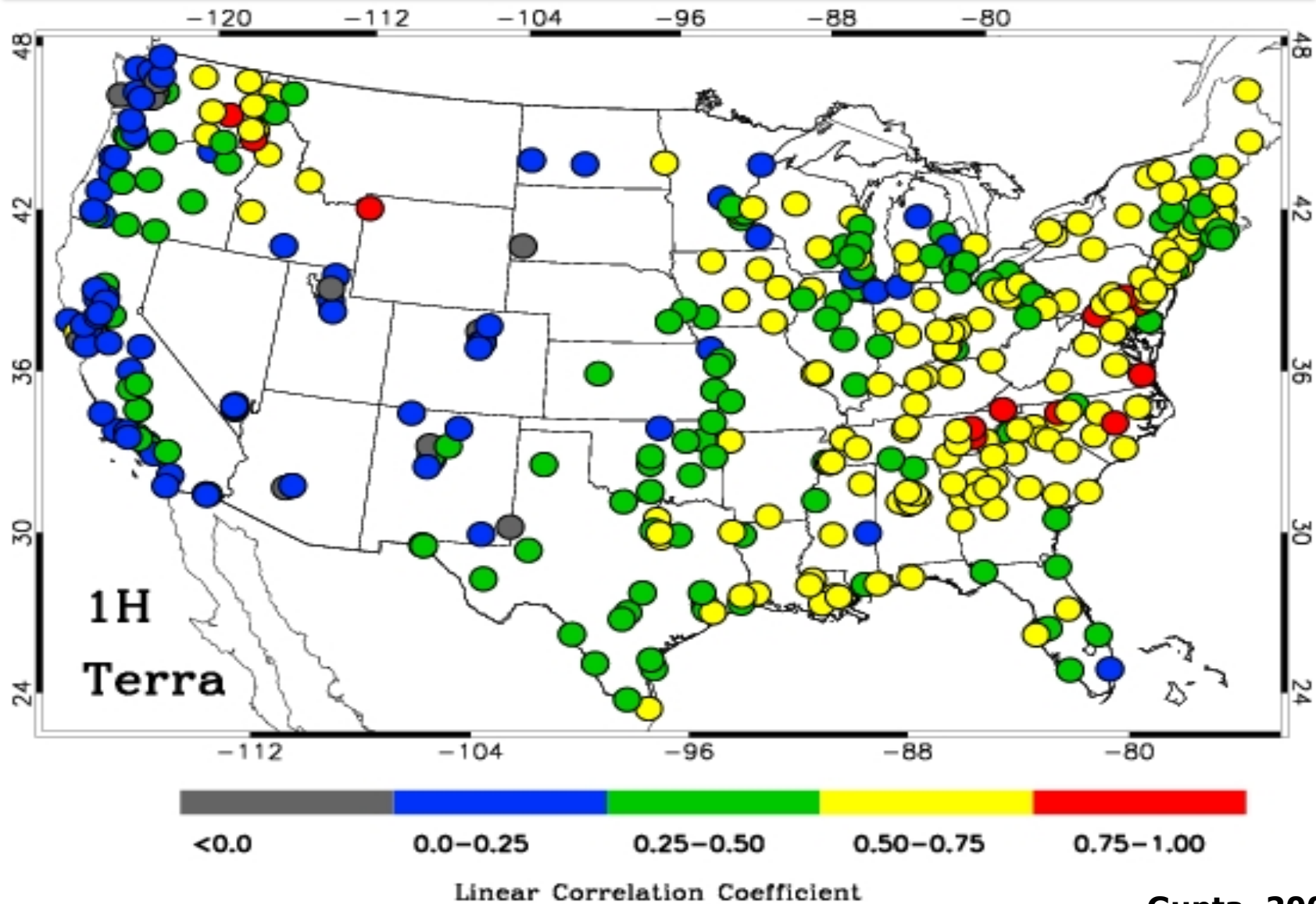
# Simple Models from Early Days



**Figure 14.** Relationship between 24-hour  $PM_{10}$  concentrations and daily averaged AERONET  $\tau_a$  measurements from August to October 2000 in northern Italy.



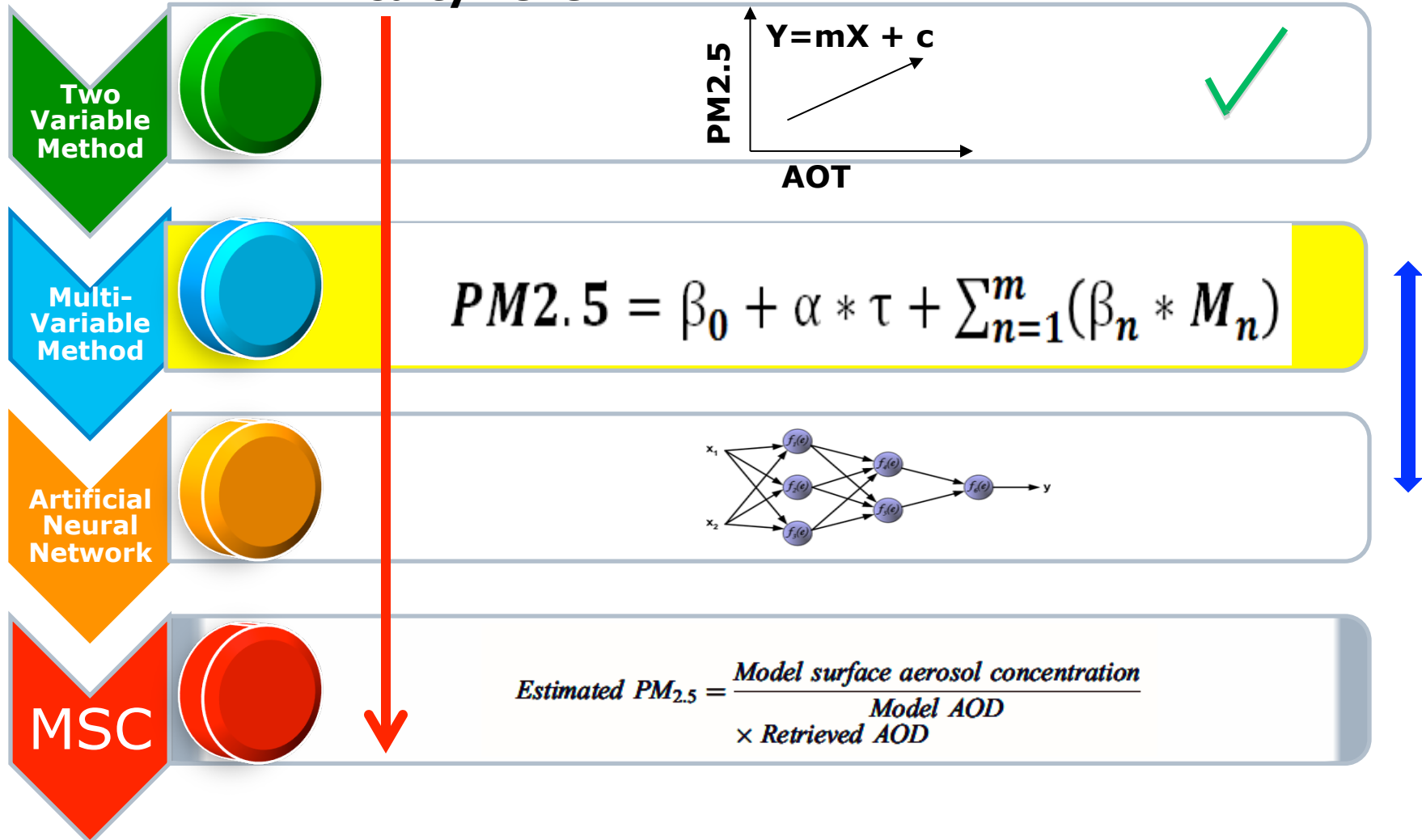
# AOT-PM2.5 Relationship



Gupta, 2008

# PM2.5 Estimation: Popular Methods

## Difficulty Level

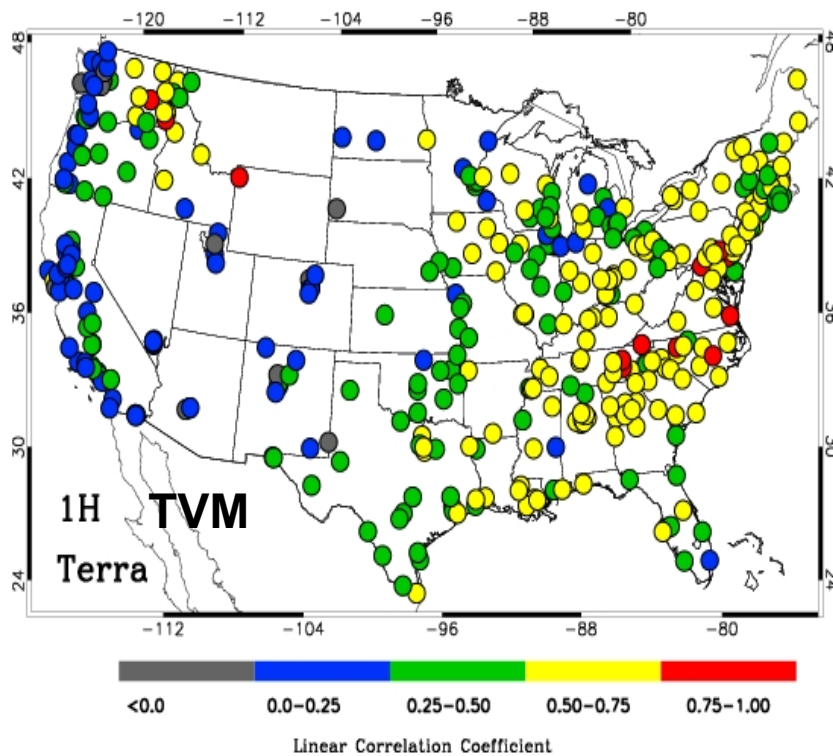


**and Empirical Methods, Data Assimilation etc. are underutilized**

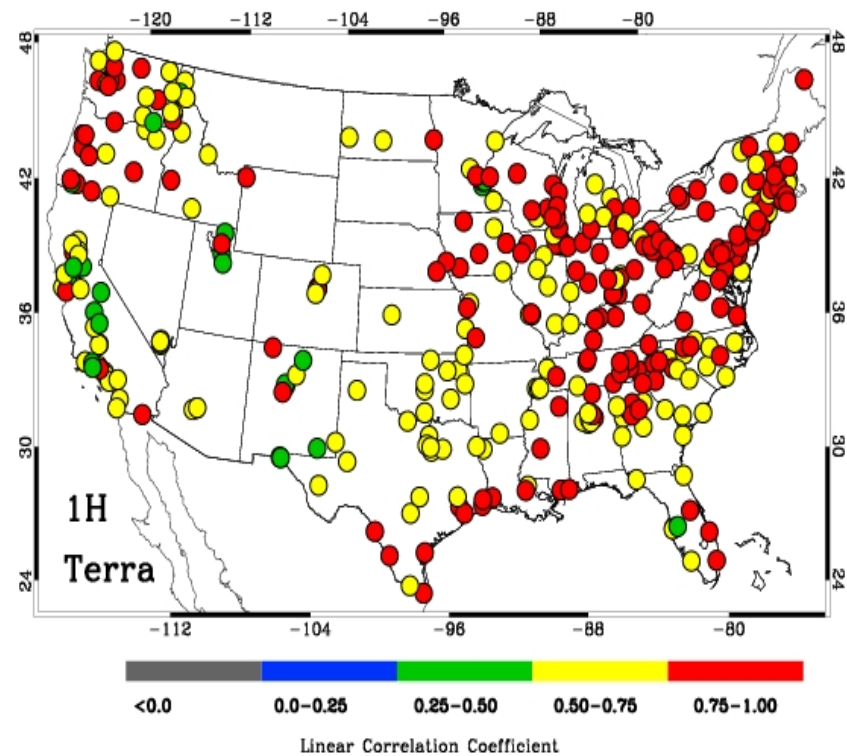


# Multi Variable Method

Predictor: AOD



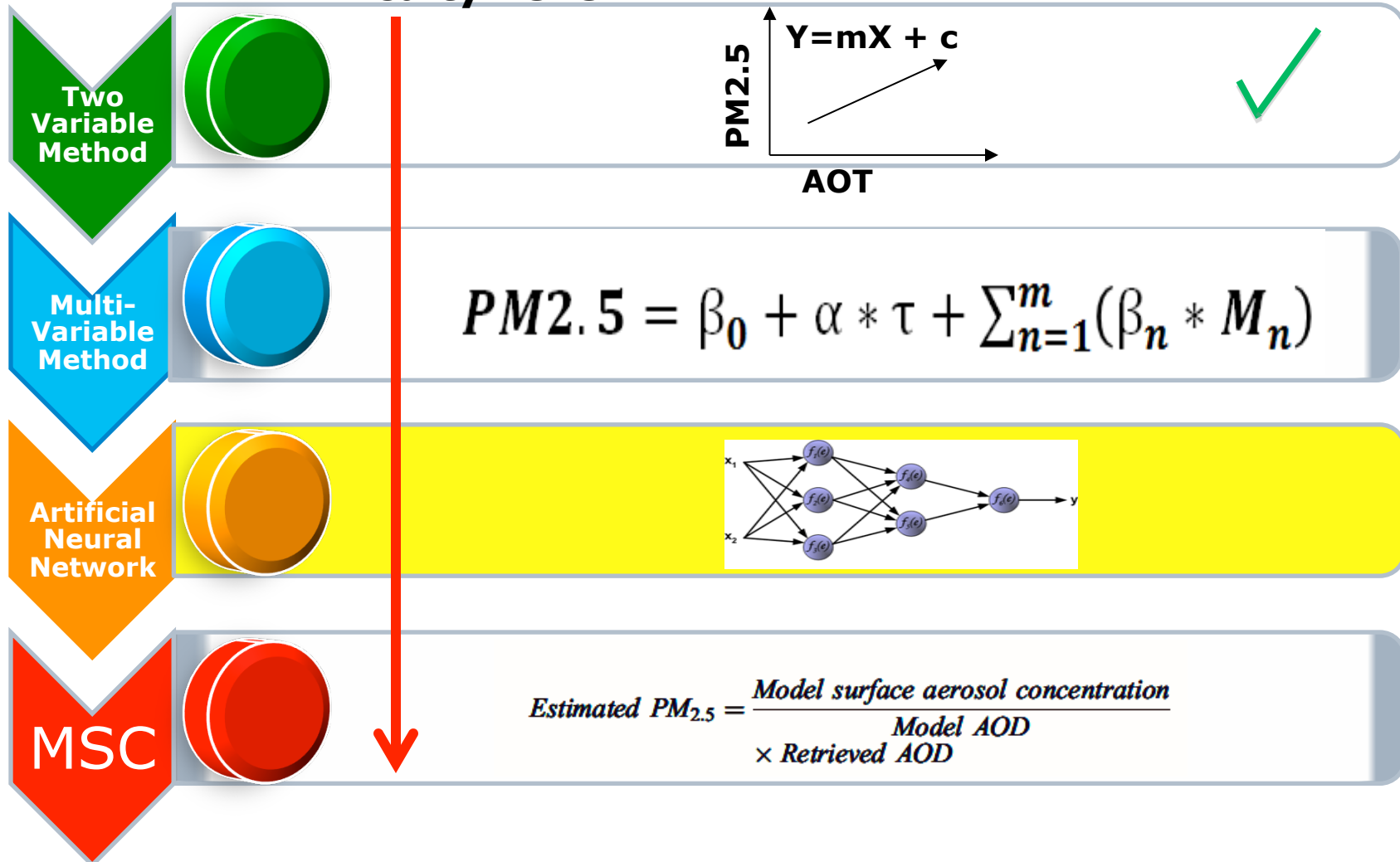
Predictor: AOD + Meteorology



**Linear Correlation Coefficient between  
observed and estimated PM<sub>2.5</sub>** Gupta, 2008

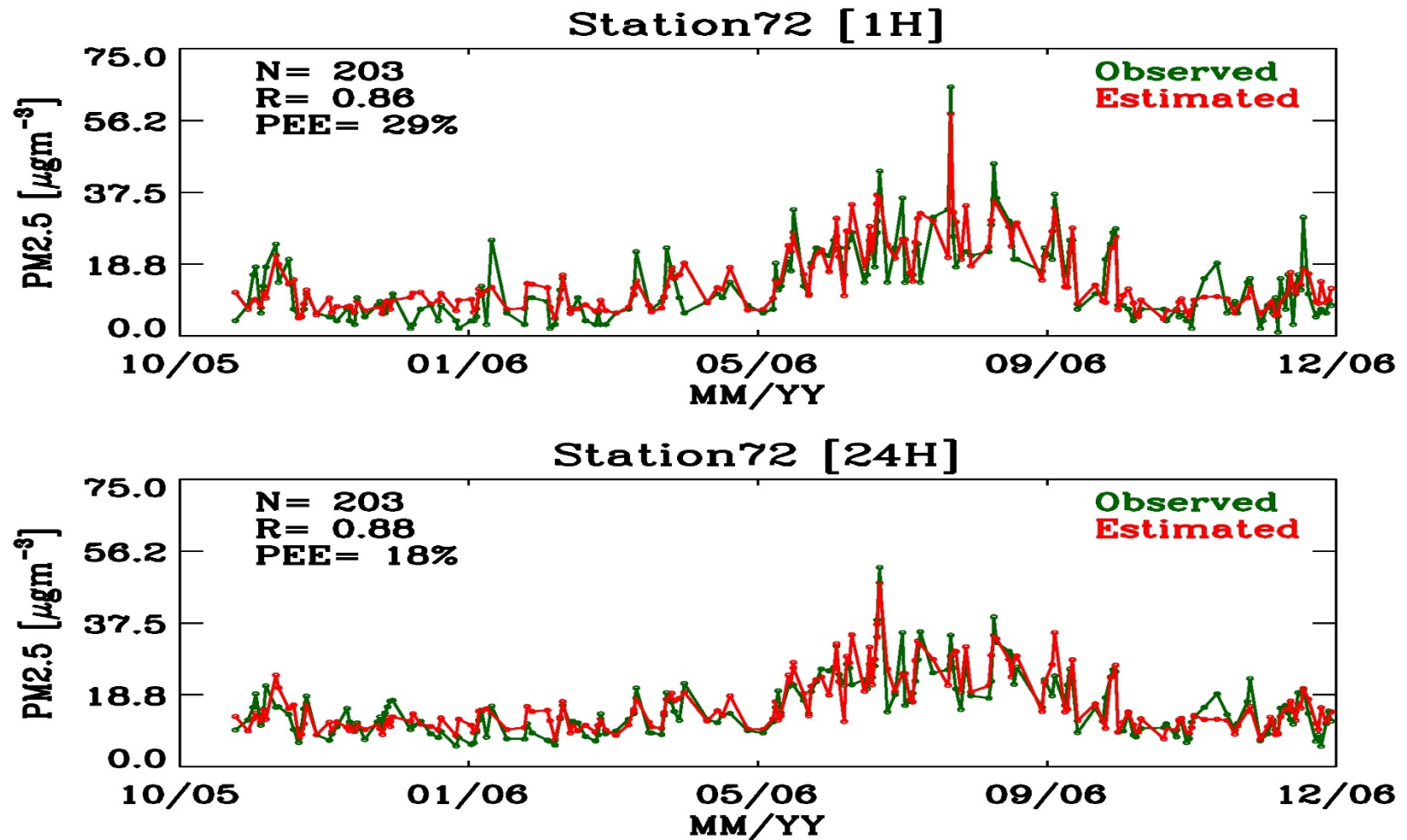
# PM2.5 Estimation: Popular Methods

## Difficulty Level

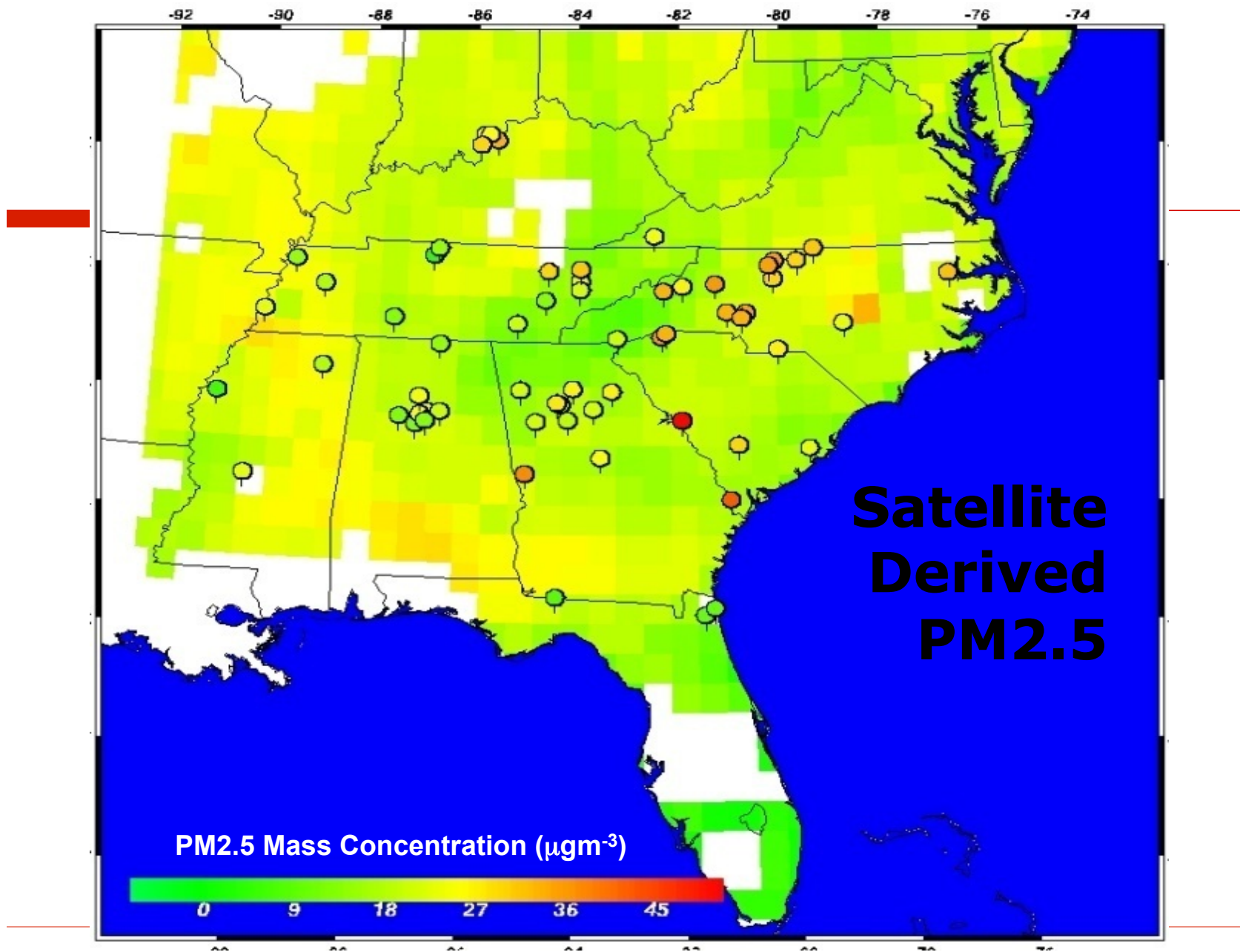


**and Empirical Methods, Data Assimilation etc. are underutilized**

# Time Series Examples of Results from ANN



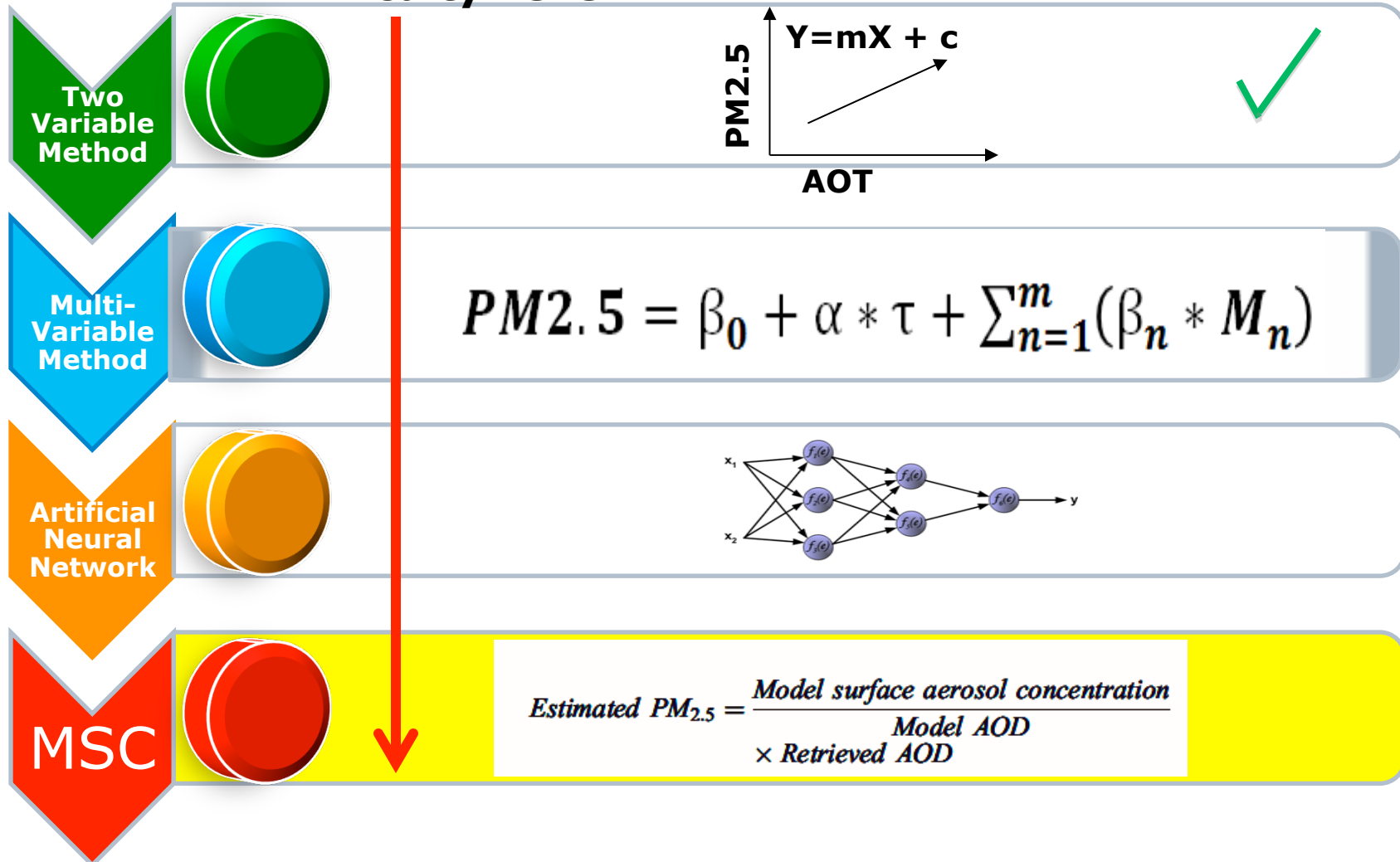




**Gupta et al., 2009**

# PM2.5 Estimation: Popular Methods

## Difficulty Level



**and Empirical Methods, Data Assimilation etc. are underutilized**

# Questions to Ask: Issues

- ✓ How accurate are these estimates?
  - ✓ Is the PM<sub>2.5</sub>-AOD relationship always linear?
  - ✓ How does AOD retrieval uncertainty affect estimation of air quality?
  - ✓ Does this relationship change in space and time?
  - ✓ Does this relationship change with aerosol type?
  - ✓ How does meteorology drive this relationship?
  - ✓ How does the vertical distribution of aerosols in the atmosphere affect these estimates?
-

# The Use of Satellite Data

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- ☐ Currently for research
  - Spatial trends of PM<sub>2.5</sub> at regional to national level
  - Interannual variability of PM<sub>2.5</sub>
  - Model calibration / validation
  - Exposure assessment for health effect studies
- ☐ In the near future for research
  - Spatial trends at urban scale
  - Improved coverage and accuracy
  - Fused statistical – deterministic models
- ☐ For regulation?



# Tradeoffs and Limitations

- ☐ **Spatial resolution – varies from sensor to sensor and parameter to parameter**
- ☐ **Temporal resolution – depends on satellite orbits (polar vs geostationary), swath width etc.**
- ☐ **Retrieval accuracies – varies with sensors and regions**
- ☐ **Calibration**
- ☐ **Data Format, Data version**
- ☐ **Etc.**

**No textbook solution!**

## 2009 CRITICAL REVIEW



R.M. Hoff



S.A. Christopher

### Raymond M. Hoff

Department of Physics and the Joint Center for Earth Systems Technology and Technology Center, University of Maryland, Baltimore

### Sundar A. Christopher

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DOI:10.3155/1047-3289.59.6  
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## Remote Sensing of Particulate Pollution from Space: Hurdles and Promises

The use of the AOD as a measure for mass concentration has skill in some regions but less in others and does not provide a uniform way to measure aerosols across the United States. We discussed in Table 4 the range of mea-

standards (NAAQS).<sup>142</sup> The 39-yr history of those standards parallels the time period that satellite meteorology and observations have developed and yet, to date, no satellite measurements have been used to quantitatively address the NAAQS. From the review conducted here, only one congress-

### IMPLICATIONS

Satellite measurements are going to be an integral part of the Global Earth Observing System of Systems. Satellite measurements by themselves have a role in air quality studies but cannot stand alone as an observing system. Data assimilation of satellite and ground-based measurements into forecast models has synergy that aids all of these air quality tools.

ellite data possible in significant exceedances only. Applications such as event identification, transport, and atmospheric composition determination are strengths of satellite measurements. Where high precision is required (compliance monitoring, the "but for" test, and quantitative measurement of visibility effects on Class I areas), satellite data are presently of limited utility.

EPA has taken a satellite observations role for itself in the Exceptional Events Rule.<sup>144</sup> If a region can show conclusively that they are being impacted by an event (a fire, a dust storm, etc.) that is outside of their jurisdiction to regulate, the event can be flagged as a nonexceedance event. This provides a significant motivation for regional

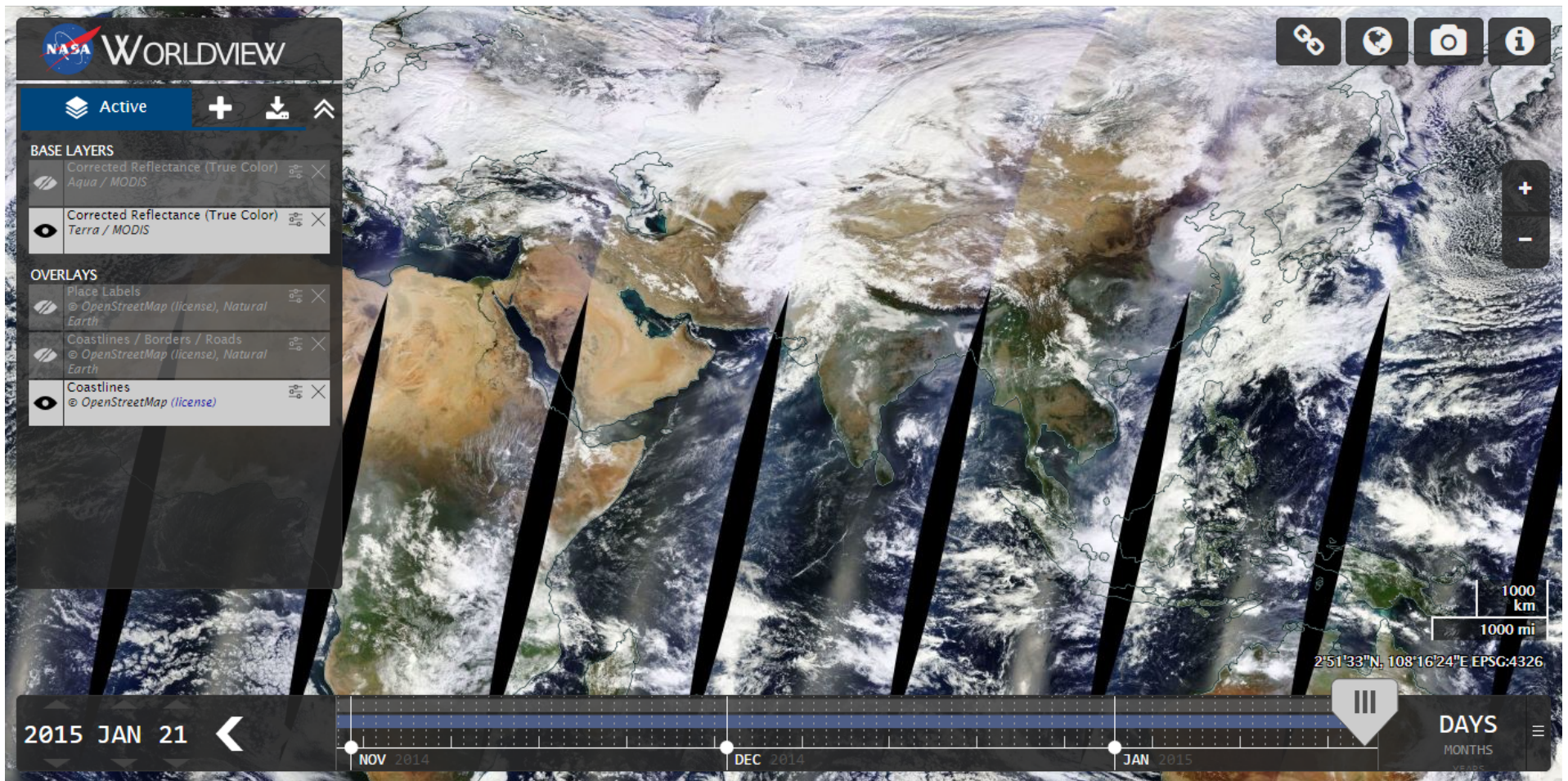
Although the desire for the use of satellite data for air quality purposes is widely stated, the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring AOD is

**Suggested Reading**



# NASA's Worldview

(<https://earthdata.nasa.gov/labs/worldview/>)



**Visualization tool for near real time  
satellite observations**

# GIOVANNI

## (Visualization and Analysis of Level 3 Satellite Products)

**EARTHDATA** Data Discovery ▾ DAACs ▾ Community ▾ Science Disciplines ▾

**GIOVANNI** The Bridge Between Data and Science v 4.16 [Release Notes](#) [Browser Compatibility](#) [Known Issues](#)

**Time-Averaged Scatter temporarily unavailable...** [1 of 2 messages] [Read More](#)

**Select Plot**

☐ Maps: *Select...* ☐ Comparisons: *Select...* ☒ **Time Series: Area-Averaged** ☐ Vertical: *Select...* ☐ Miscellaneous: *Select...*

**Select Date Range (UTC)**  
YYYY-MM-DD HH:mm  
2002 -07 -01 00 :00 to 2015 -07 -31 23 :59  
Valid Range: 1979-01-01 to 2015-09-28

**Select Region (Bounding Box or Shapefile)**  
Format: West, South, East, North  
-180, -90, 180, 90 [Show Map](#) [Show Shapes](#)

**Select Variables**

▼ **Disciplines**

- ☒ Aerosols (128)
- ☐ Atmospheric Chemistry (36)
- ☐ Atmospheric Dynamics (125)
- ☐ Cryosphere (5)
- ☐ Hydrology (238)
- ☐ Ocean Biology (10)
- ☐ Oceanography (8)
- ☐ Water and Energy Cycle (248)

▼ **Measurements**

- ☐ Aerosol Index (3)
- ☐ Aerosol Optical Depth (2)
- ☐ Albedo (7)
- ☐ Angstrom Exponent (16)
- ☐ Component Aerosol Optical Depth (7)
- ☐ Statistics (28)
- ☐ Total AOD Climatology Anomaly (6)

Number of matching Variables: 128 of 570  
Please select at least 1 variable

Keyword :  [Search](#) [Clear](#)

	Variable Name	Source	Temp. Res.	Spat. Res.	Begin Date	End Date	Units	Vert. Slice
<input type="checkbox"/>	<a href="#">Aerosol Angstrom Exponent 550/865 nm (Dark Target, Ocean-only) (MOD08_D3 v051)</a>	MODIS-Terra	Daily	1 °	2000-03-01	2015-09-26	-	-
<input type="checkbox"/>	<a href="#">Aerosol Angstrom Exponent 470/660 nm (Dark Target, Land-only) (MOD08_D3 v051)</a>	MODIS-Terra	Daily	1 °	2000-03-01	2015-09-26	-	-
<input type="checkbox"/>	<a href="#">Aerosol Optical Depth 550 nm (Dark Target) (MOD08_D3 v051)</a>	MODIS-Terra	Daily	1 °	2000-03-01	2015-09-26	-	-
<input type="checkbox"/>	<a href="#">Pixel Count of Aerosol Optical Depth 550 nm (Dark Target) (MOD08_D3 v051)</a>	MODIS-Terra	Daily	1 °	2000-03-01	2015-09-26	-	-
<input type="checkbox"/>	<a href="#">Aerosol Optical Depth 550 nm (Deep Blue, Land-only) (MOD08_D3 v051)</a>	MODIS-Terra	Daily	1 °	2000-03-01	2007-12-31	-	-
<input type="checkbox"/>	<a href="#">Aerosol Angstrom Exponent 550/865 nm (Dark Target, Ocean-only) (MOD08_D3 v051)</a>	MODIS-Aqua	Daily	1 °	2002-07-04	2015-09-17	-	-


[Help](#) [Reset](#) [Feedback](#) [Plot Data](#)

Responsible NASA Official: [Steven.J.Kempner@nasa.gov](mailto:Steven.J.Kempner@nasa.gov) Powered By: [Contact Us](#)

<http://giovanni.sci.gsfc.nasa.gov/>



# Python Tools

**ARSET**  
Applied Remote Sensing Training

Search

DISASTERS

ECO FORECASTING

HEALTH & AIR QUALITY

WATER RESOURCES

**Health & Air Quality**



























- ▶ Air Quality Webinars
- ▶ Air Quality Workshops
- ▶ Applications
- ▼ Tools
  - Python Scripts
  - Polar Orbit Satellite
- Air Quality Personnel

**Upcoming Training**

**Ecoforecasting**  
NASA Remote Sensing for Wildfire Applications  
10/06/2015 to 10/08/2015

**Airquality**  
Satellite Remote Sensing of Particulate Matter Air Quality: Data, Tools, Methods and

Python Scripts for Aerosol Data Sets from MERRA, MODIS, and OMI:

Number	Purpose/Objective	MODIS-HDF4	OMI-HDF5	MERRA-netCDF4
1	To extract aerosol data from a file and create a map of the resulting data	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>
2	To view info about a variety of SDS from a file, both generally and at a specific lat/lon	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>	
3	To print all SDS from a file	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>
4	To save a file in ASCII format: saves time, lat, lon, and other SDS dependent on file type	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>	 <a href="#">Script</a>  <a href="#">README</a>
5	To extract AOD data from a MODIS HDF4 file, calculate PM2.5 from the data, and create a map of the results	 <a href="#">Script</a>  <a href="#">README</a>		
6	To read a list of MODIS HDF4 files, and grid AOD to a user-defined grid size	 <a href="#">Script</a>  <a href="#">README</a>		

# Some online tools



### About the U.S. Air Quality Weblog

USAQ is a daily diary of air quality in the U.S. prepared using information from satellites, ground-based measurements, and models. Interpretation and analysis are provided by the staff of the **University of Maryland, Baltimore County Atmospheric Lidar Group**.

Permission has been sought for the use of copyrighted images, data, and products on USAQ. Similarly, we request any data copied from this site carry the citation "Image (or graphic) obtained from the U.S. Air Quality Smog Blog (<http://alg.umbc.edu/usaq/>)."


### Recent Posts

- 20 Apr: **Weekend Edition: Air quality is generally good across US except Ozone coming up in California**
- 19 Apr: **Good Air quality over nation, Large Smoke Plume over Gulf of Mexico**
- 18 Apr: **Dense smoke from Mexico continues moving to Texas**
- 17 Apr: **Fires in the Yucatan Peninsula and Unhealthy PM2.5 AQI in Texas**
- 16 Apr: **Fire activity in the Southeast increases AOD as it moves north.**
- 15 Apr: **Large area of smoke over Gulf; Elevated PM2.5 in south**
- 13 Apr: **Weekend Edition: fire season in Central America; Moderate PM in Southern California**

### Recent Comments







- 18 Apr: **Michael Bara on Fires in the Yucatan**




<http://alg.umbc.edu/usaq/>



**IDEA** Infusing satellite Data into Environmental Applications

We value your feedback! Please send any comments, problems and suggestions to the IDEA Team.

MODIS (Terra)

MODIS (Aqua)

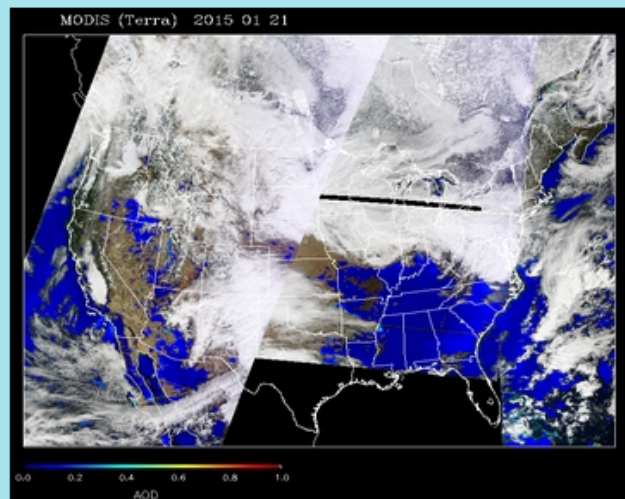
GASP

GASP WEST

VIIRS CONUS

VIIRS OCONUS

**Plots of MODIS Terra RGB and aerosol optical depth (AOD)**



MODIS (Terra) 2015 01 21

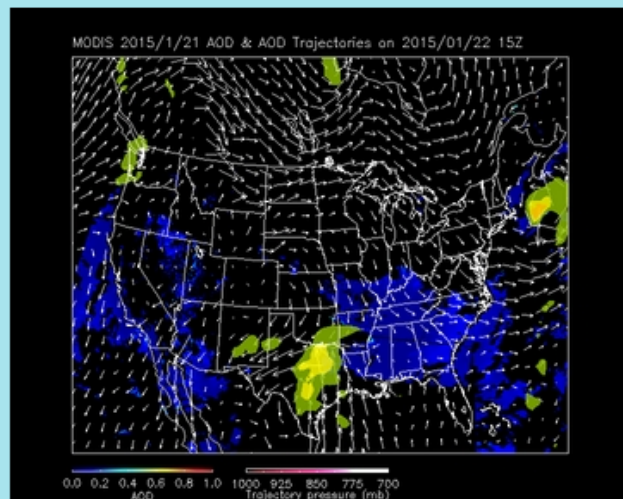
0.0 0.2 0.4 0.6 0.8 1.0  
AOD

Select Region

*Product description*

3-day composite history\*

**48-hour aerosol trajectory forecast, with model winds and precipitation**



MODIS 2015/1/21 AOD & AOD Trajectories on 2015/01/22 15Z

0.0 0.2 0.4 0.6 0.8 1.0  
AOD

1000 925 850 775 700  
Trajectory pressure (mb)

View latest

*Product description*

PM2.5 Estimation from AOD

**Data are only available for US region**

<http://www.star.nesdis.noaa.gov/smcd/spb/aq/>

# AIRNow Satellite Data Processor


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## The AIRNow Satellite Data Processor (ASDP)

is a system under development that enables blending (or fusing) of surface PM<sub>2.5</sub> measurements and satellite-estimated PM<sub>2.5</sub> concentrations to provide additional air quality information to AIRNow in regions without existing surface air quality monitoring networks.

The ASDP system builds the capacity and framework necessary to implement satellite data as these data become available to the air quality community. This project is being funded by the NASA Applied Sciences Program.



 [Log In to Learn More](#)

[airnowtech.org](http://airnowtech.org)

---

**Data are only available for US region**

# Air Quality Mini Project

([http://arset.gsfc.nasa.gov/sites/default/files/airquality/webinars/AOD\\_PM/Webinar\\_MiniProject\\_Guidelines\\_forwebpage.pdf](http://arset.gsfc.nasa.gov/sites/default/files/airquality/webinars/AOD_PM/Webinar_MiniProject_Guidelines_forwebpage.pdf))

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## Important Dates:

- ❑ **October 15, 2015: Project Title, Team Members, and other Details are Due.** [Enter Your Project Information](#)  
(Information can be entered before the deadline)
- ❑ **November 10, 2015: Project Presentation (not more than 5 slides) due.**
- ❑ **More information on the project submission will be available close to the deadline.**
- ❑ **November 20, 2015: Project Presentation – more details will follow soon.**



# Air Quality Mini Project

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- ❑ **Disclaimer: All projects suggested or completed as part of this webinar series are exclusively for the purpose of learning and may not be used for publications, reports or any kind of official document, presentation, or paper. NASA ARSET is not responsible for providing any kind of formal review of the research conducted as part of this webinar project.**
- ❑ **Participants are encouraged to work on this project as a team of 2-10 people but it is not mandatory and you can work individually as well. NASA-ARSET program will not assist in forming and managing project teams.**

# Air Quality Mini Project

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- ☐ **All projects must have a satellite component. Participants are highly encouraged to use data, tools, and methods covered during this webinar series. Previously done projects and research cannot be submitted.**
-

# Air Quality Mini Project – Suggested Topics

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- ❑ **PM2.5 Estimation using Satellite Data:** Estimate PM2.5 over a certain region or place using satellite, surface and model data sets. You can use any method (or methods) to make your estimations, and can use your own PM2.5 data or download some from SPARTAN/AirNow networks or other sources. Please see the suggested resources and tools section for further details.
- ❑ **Long Term Trend Analysis:** Perform long-term air quality trend analysis over a certain region or place using satellite observations, while supporting results with surface measurements. Regional trends can be performed using level 3 satellite data sets as long as errors and uncertainties involved are known and discussed.
- ❑ **Transport of smoke, dust, and/or volcanic emissions:** Perform a case study analysis of certain air quality event in the region of interest. Analyze the impact of smoke or dust transport on the local and regional air quality using multiple data sets, tools and models.
- ❑ **Your own project:** This air quality project is not limited to topics suggested above. If you have other ideas, you are more than welcome to define your own project.

# Home Work – Week 2

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**Perform time series analysis of aerosol optical depth using MODIS L3 monthly mean data over selected region of 5x5 degree. Analysis is performed using GIOVANNI and EXCEL.**

**<http://goo.gl/forms/KUzkGollso>**

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